RADIATIVE CAPTURE OF RESONANCE NEUTRONS BY THE Pr^{141} *NUCLEUS*

JAN URBANEC

Joint Institute for Nuclear Research

Submitted to JETP editor March 13, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 93-97 (August, 1963)

A single-crystal scintillation spectrometer was used to measure the spectra of hard 3—7.5 MeV γ quanta emitted as a result of capture of resonance neutrons by the Pr^{141} nucleus. The relative intensities of the ground-state transition for the first six resonances are determined on the basis of these measurements. Conclusions regarding the nature of the 85.1 eV resonance are deduced from the shape of the γ spectra.

CONSIDERABLE interest is attached to nuclei with a near-magic number of neutrons from the point of view of fluctuations of the radiation widths. In such nuclei large fluctuations are expected in all the characteristics of the neutron resonances, in view of the low level density or in view of the existence of energy regions where levels of one parity predominate. Measurements have shown that the total radiation widths Γ_γ of the resonances of Pr^{141}[1], which is magic in the neutron number, are one third as large at the 85.1 eV resonance as at the remaining resonances.

Corge et al[2] measured the spectra of hard gamma quanta in three resonances of Pr^{141}. According to [2], the ground-state transition, the energy of which is known from measurements of the gamma rays emitted upon capture of thermal neutrons[3], practically disappears in the 85.1 eV resonance. On the basis of these measurements, the low radiation width in the 85.1 eV resonance is due to the fact that this resonance is of the p-wave type. The latest measurements give for the width Γ_γ at the 85.1-eV resonance a value one-and-a-half times smaller than the remaining ones [4]. Our investigation was devoted to a measurement of the spectra of hard gamma rays for a large number of Pr^{141} resonances, with a check on the rather interesting deduction [2] that the 85.1-eV resonance is of the p-wave type.

MEASUREMENT PROCEDURE AND RESULTS

The measurements were made on the fast pulsed reactor (FPR) of the Joint Institute for Nuclear Research[5]. The gamma-spectrum measurements were made with a single-crystal scintillation spectrometer with an NaI(Tl) crystal measuring 10.5 by 10.5 cm and having a resolution of 5% at the total absorption peak of the 4.43 MeV line. The scintillation spectrometer was located 100 meters away from the pulsed reactor. Under these conditions, the resolution of the neutron spectrometer was 0.4 μ-sec/m. The three-dimensional spectrum was recorded on a magnetic tape to register the spectrometer pulses[6].

We used in the measurements a simple geometry, which is shown schematically in Fig. 1. The specimen with a 13 × 10 cm cross section contained approximately 150 grams of praseodymium oxide in powdered form.

The gamma spectrum was investigated in six resonances: 85.1, 216, 239, 359, 384, and 515 eV (the resonance energies are taken from Wang et al[4]). The 216- and 239-eV resonances as well as the 359- and 385-eV resonances were not resolved in our apparatus, so that the amplitude spectra belonging to each resonance were taken on the corresponding sides of the complex peaks that appear in the time distribution.

By way of illustration, Fig. 2a shows the course of the time distribution in the region of amplitudes corresponding to a gamma-ray energy of 3 MeV, while Fig. 2b shows the course of the time distribution for 5.8-MeV gamma quanta. The width of the amplitude channel was 200 keV in both cases.

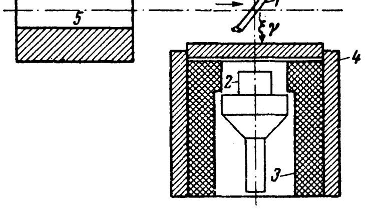

FIG. 1. Schematic drawing of the apparatus: 1 – specimen, 2 – detector crystal, 3 – lead shield, 4 – shield made of B_4C with paraffin, 5 – collimator made of B_4C with paraffin.

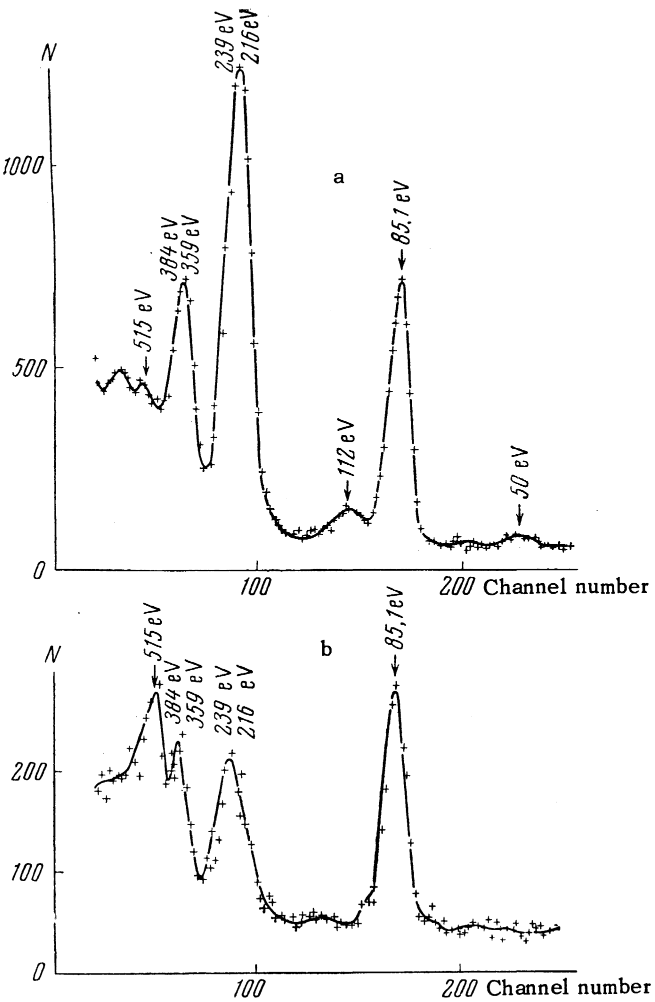

FIG. 2. Time distributions (spectra): a – spectrum at 3 MeV gamma-ray energy; b – spectrum at 5.85 MeV gamma-ray energy. Channel width in both cases is 200 keV.

Figures 3a and b show the spectra of 3—7.5 MeV hard gamma rays corresponding to the individual resonances.

From the spectra obtained we determined the partial radiation widths Γ_γ of the 5.85-MeV transition for all six resonances. The partial radiation width of the 85.1-eV resonance was determined from the summary number of pulses in the total absorption peak at 5.85 MeV. We used here the value $\Gamma = 8.1 \times 10^{-2}$ eV, in accordance with [1,4].

The partial radiation width Γ_γ (5.85 MeV) for the remaining resonances was calculated on the basis of the relative intensities, which we determined using the radiation widths of Wang et al[4]. In this procedure we did not subtract the fraction belonging to the transition to the first excited level. The results of the calculations are listed in the table.

Unlike Corge et al[2], who did not observe a ground-state transition for the 85.1-eV resonance, we did observe this transition, with an even larger relative intensity than in the 216- and 239-eV resonances. This is shown in column 2 of the table, which gives a comparison of the ratios of the intensities of the 5.85-MeV gamma transition to the intensity of the apparatus spectrum at 3.0 MeV

E_n, eV	$\left[\frac{I_\gamma (5,85)}{I_\gamma (3,0)}\right]_{rel}$	Γ_γ (5,85 MeV) ×10³, eV
85.1	1	7.5±2
216	0.4±0.1	3.6±1
239	0.41±0.1	4.3±1
359	0.42±0.1	3,0±1
384	0.94±0.15	~11
515	2±0.5	~13

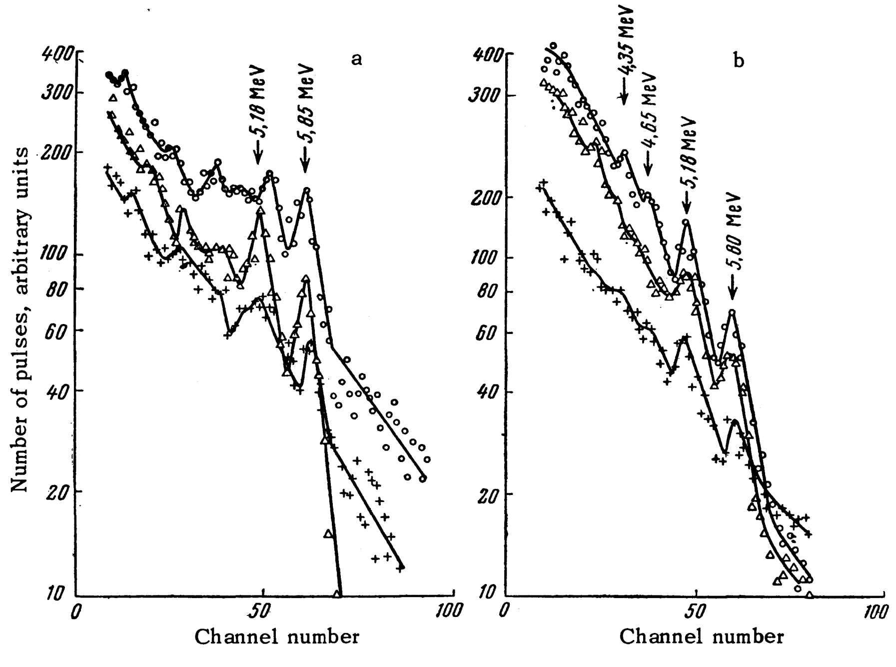

FIG. 3. Apparatus spectrum of high-energy gamma-rays: a – spectra in 85.1 (Δ) 384 (+) and 585 (o) eV resonances; b – gamma-ray spectra in 216 (o), 239 (Δ) and 359 (+) eV resonances.

for different resonances. The unit chosen is the ratio of intensities $I_\gamma(5.85)/I_\gamma(3.0)$ for the 85.1 eV resonance.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

The s-neutron is captured at a Pr^{142} level with characteristics 2^+ or 3^+. The ground-state level of Pr^{142} has exactly determined spin and parity 2^-.

In this case the compound nucleus can go over into the ground state via high-intensity electric dipole transition. In the case of p-neutron capture, the capture level has negative parity and four possible spin values. The characteristics of the low-lying levels of Pr^{142} are unknown. If a level with positive parity were to exist close to the ground state, we could observe an electric dipole transition with energy close to the neutron binding energy even in the p-neutron capture. Since the accuracy with which energy is determined in a scintillation spectrometer does not exceed ±50 keV in the investigated region, such a transition could not be distinguished from a ground-state transition and no conclusive evaluation of the character of the 85.1-eV resonance could be made.

However, we can draw for the Pr^{142} nucleus the following conclusions with respect to the parities of the low-lying levels. Below the pair-breaking energy, all the Pr^{142} levels are due to the configuration of states of the last neutron in excess of the closed shell and of the last proton in excess of the closed subshell. Since these particles are in the lowest states of the corresponding shells, we can expect all the levels below the pair-breaking energy to have negative parity. Since the first excited level of the Pr^{141} nucleus has positive parity and the first excited level of the Nb^{143} nucleus has negative parity, and since the characteristics of the ground state of Pr^{142} have no anomalies whatever, we can without doubt propose that at least the first excited level of Pr^{142} has negative parity. It follows from this that capture of s-neutrons should also cause an intense transition to the first excited level of Pr^{142}. A 5.85-MeV ground-state transition and an adjacent 5.67 MeV transition are observed in the capture of thermal neutrons[3]. For the same reasons as above, the energy difference of these two transitions is equal to the energy of the first excited state. In turn, there can be no level with positive parity in the energy region up to ~ 160 keV. In this case, capture of s-neutrons should produce in the Pr^{142} gamma-ray spectrum intense transitions with energies 5.67 and 5.83 MeV, while capture of p-neutrons should cause practically no transitions in this energy range.

The positions and the forms of the peaks in the spectra obtained by us indicate that both transitions, 5.67- and 5.83-MeV, appear in the 216, 239, and 359 eV resonances, while the ground-state transition even predominates in the 85.1-, 384-, and 515-eV resonances. It is clear, therefore, that the 85.1-eV resonance is an s-resonance, for in capture of p-neutrons the ground-state transition would be of M1 type, and its partial width would be smaller than the partial widths of this transition in the remaining resonances.

Our conclusion that the 85.1-eV level is not a p-resonance is also favored by the following circumstance. Theory predicts for the strength function of the p-neutrons in the given mass region a value $\bar{\Gamma}_n^{(1)}/\bar{D} < 2 \times 10^{-4}$[7]. The experimental values in this mass region do not exceed the theoretical predictions. For Pr^{142} we obtained for the average distance between levels of one spin $\bar{D} \cong 200$ eV (assuming an equal number of levels of both spins and neglecting the weak levels entirely). In such a case, the average reduced neutron width for p-resonances has a value $\bar{\Gamma}_n^{(1)} < 4 \times 10^{-2}$ eV. The reduced neutron width for the 85-eV level turns out to be in the case of p-resonance $\Gamma_n^{(1)} = 4$ eV, and the ratio is $\chi_0 = \Gamma_n^{(1)}/\bar{\Gamma}_n^{(1)} > 10^2$. Using a Porter-Thomas distribution, we can determine the probability for the existence of a level with $\chi > 10^2$. The greatest probability of observing such levels will be obtained from a distribution with $\nu = 1$. We find that when $\nu = 1$ the existence of such a p-level is practically excluded, since the probability of its appearance is $w(\chi > 10^2) < 2 \times 10^{-23}$.

The spectra of the hard gamma quanta have approximately the same form in the 85.1-, 384-, and 515-eV resonances. These spectra differ from the gamma spectra of the other measured group of Pr^{141} levels in having a larger intensity in the entire part of the spectrum in the region from 3.5 MeV to the neutron binding energy. Since a large number of lines appears in this region, this difference cannot be attributed to fluctuations of the partial radiation widths, but can be ascribed to different values of the spin of the capture level in both resonance groups. In addition, these level groups have different reduced neutron widths, which are one or two orders of magnitude lower in the 85.1- and 384-eV resonances than in the remaining resonances.

The closeness of the magic numbers has a similar influence on the dependence of Γ_n on the capture-level spin in Se^{77} and Y^{89}[8]. Adhering to the conclusion of [1] that the spins and parities of the 216- and 239-eV levels are 3^+, we can assume that the capture level in the 85.1- and 384-eV resonances has characteristics 2^+. This conclusion can be made more precise by measuring the spins of the low-lying Pr^{142} levels.

In conclusion, the author is grateful to I. M. Frank, F. L. Shapiro, and Yu. S. Yazvitskiĭ for interest in the work and for discussions of the results, to G. P. Zhukov for setting up the tape recorder, and to the rest of the staff for continuous help with the work.

---

[1] Corge, Huynh, Julien, Morgenstern, and Netter, J. phys. radium **22**, 719 (1961).

[2] Corge, Huynh, Julien, Morgenstern, and Netter, J. phys. radium **22**, 724 (1961).

[3] Groshev, Demidov, Lutsenko, and Pelekhov, Atlas spektrov γ-lucheĭ radiatsionnogo zakhvata teplovykh neĭtronov (Tables of Thermal-neutron Radiation-capture γ-ray Spectra), GUAÉ, 1958.

[4] Wang, Iliescu, Karzhavina, Kim, Pikel'ner, Popov, Stadnikov, Sharapov, and Yazvitskiĭ, Preprint, Joint Inst. Nuc. Res., 1963, in press.

[5] Blokhin, Blokhintsev, Blyumkina, et al, Atomnaya énergiya **10**, 437 (1961).

[6] Zhukov, Zabiyakin, Shibayev, et al, Preprint, Joint Inst. Nuc. Res. R-1127, 1962.

[7] B. Buck and F. Perey, Phys. Rev. Lett. **8**, 444 (1962).

[8] Julien, Corge, Huynh, Morgenstern, and Netter, Phys. Lett. **8**, 67 (1962).

Translated by J. G. Adashko
18